Fusion of airborne and spaceborne images in visible range

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Operational Remote Sensing for Sustainable Development, Nieuwenhuis, Vaughan & Molenaar (eds)
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ABSTRACT: The fusion of airborne and spaceborne images allows to benefit from the high spatial resolution of airborne images with the high spectral resolution and the high repetitivity of satellite data. In this paper, the problem of improving the spatial resolution of satellites images is addressed, by taking advantage of the simultaneous availability of airborne images over the same areas. The proposed process of fusion, based on the ARSIS concept (Ranchin *et al.*, 1998), allows the improvement of the spatial resolution of images with respect of their original spectral content. First, we focus on the general requirements and hypothesis of a sensor fusion method. Then, the different problems involved by such a merging method are reviewed. The ARSIS concept is presented and its application to the merging of airborne and spaceborne images is described. An example and its evaluation based on the method proposed by Wald *et al.* (1997) is proposed.

1 INTRODUCTION

In the field of Earth observation, airborne and spaceborne remote sensing are often compared and opposed. Due to their major differences and capabilities, users make their choice according to the application, its budget and their availability, one or the other.

The airborne images led usually to a more accurate geometric description of the features on Earth than satellite ones. In airborne image, the atmospheric effects are less important due to the altitude of flight of the plane carrying the sensor and are often neglected. If the sky is too cloudy or if the light conditions are not satisfactory, the acquisition can be delayed for some hours or days. But, if the remotely sensed images are acquired using a photographic camera, some distortions in the borders of the pictures occur due to the lenses. The calibration of the images is difficult and the quality of the images is highly variable due to the possible variation in quality of the photographic film and if they are transformed in digital form, on the quality of the scanner and on its accuracy.

If the image is acquired by a pushbroom camera, distortions occur due to the variation of attitude of the plane (roll, yaw and pitch distortions). The image needs important geometrical corrections. In addition, the swath of the airborne image is limited compared to the satellite one.

The satellite images are usually less accurate in space than the airborne ones. The geometrical distortion due to the objective of the sensor is more often negligible compared to those of the airborne one. The satellite needs no authorisation for the survey of an area, and can deliver regularly images from the same area. A lot of controls are achieved on the quality of the images before they are delivered to the customer. But they are more sensitive to the atmospheric effects than the airborne ones and delay for an image of good quality often occurs due to the cloud coverage.

Users of remotely sensed images often want to take the best of the two worlds: the high spatial resolution of airborne images and the high repetitivity, high spectral resolution of satellite ones. Improvement of the spatial resolution of satellite images is one answer to this requirement. It is the actual tendency of the constructors. The declassification of part of the American military technology leads to the future launches of sensor with a high spatial resolution equal or less than one meter.

But sensor fusion can be another answer. In this problem, sensor fusion leads to the construction of high spatial resolution images by combining satellite and airborne images. Many sensor fusion methods exists. Only a few of them allow the synthesis of the images with respect to their original spectral content. The ARSIS concept (from its French name Amélioration de la Résolution Spatiale par Injection de Structures which means improvement of the spatial resolution by injection of structures) was designed to fulfil this aim. In the next paragraph, the concept is presented and its application to the case of the merging of airborne and spaceborne image exposed. Then, an example is presented on the case of the fusion of simulated SPOT 5 and airborne images. An evaluation is proposed and the results and perspectives are discussed.

2 THE ARSIS CONCEPT

The ARSIS concept makes use of the wavelet transform and the multiresolution analysis. The multiresolution analysis allows the computation, from an original image, of coarser and coarser approximations. In this scheme, the wavelet transform represents the difference of information between two successive approximations. These tools are often represented using a pyramidal scheme (Figure 1).

A more complete presentation of these tools in the field of remote sensing can be found in Ranchin (1997).

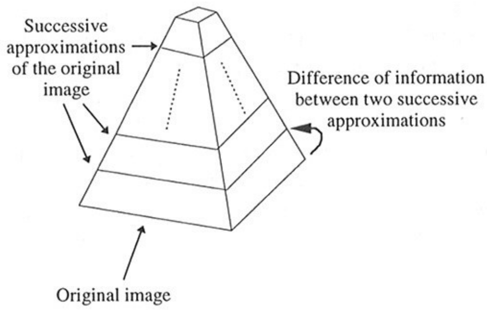


Figure 1. Representation of the successive approximations of an image by the means of a multiresolution algorithm

For all the merging processes, some pre-requisites are needed:

- images shall have different spatial and spectral resolutions,
- images to merge shall represent the same area,
- images shall be accurately registered,
- no major change shall occurred on the area during the interval between time acquisition of the source images.

If the last requirement is not satisfied, the aim of the merging process can be the updating of the observed area (Ranchin, Wald, 1996a). These requirements are not limiting the merging process to images acquired by the same platform. It was successfully applied to the merging of the SPOT XSi and P images (Ranchin *et al.,* 1994), to the merging of Landsat Thematic Mapper band 6 (120 m) with the other bands of the Thematic Mapper instrument (30 m) (Ranchin, 1993), to the merging of the Landsat Thematic Mapper bands (30 m) with the SPOT P image (10 m) (Blanc *et al.,* 1996) and to the merging of the SPOT XSi images with the image from the Russian panchromatic sensor KVR-1000 (2 m) (Ranchin *et al.,* 1996a). It was also demonstrated that this method can be applied for the SPOT 4 (Ranchin, Wald, 1996b) and the SPOT 5 (Ranchin *et al.,* 1996b; Couloigner *et al.* 1997) missions.

This process can also apply to the merging of images acquired by airborne and spaceborne sensors. Many methods have been proposed to enhance the spatial resolution of images taking advantages of the presence of one or more images with a better spatial resolution (see for example Carper *et al.,* 1990; Chavez *et al.,* 1991). But, if one of the objectives is to bring each image at the best spatial resolution available, while retaining all the spectral content of the image to enhance, only a few of them satisfy it. A comparison of the most representative merging processes has been achieved by Wald *et al.* (1997).

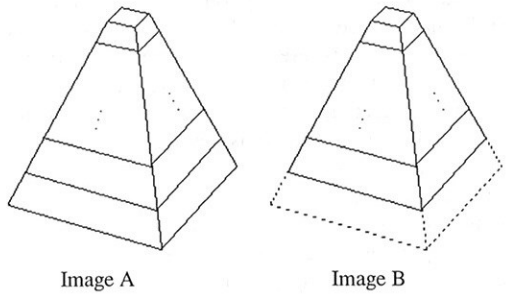


Figure 2. The use of the multiresolution analysis in the ARSIS method.

In order to fulfil this objective, the ARSIS method was first designed for the SPOT imagery and then generalised to the merging of images with different spatial and spectral resolutions. This method uses the wavelet transform and the multiresolution analysis to decompose the two images to be merged as in Figure 2.

A multiresolution analysis using the wavelet transform is applied to image A and image B, describing image A and image B at different spatial resolutions and the differences of information between the successive approximations of image A and image B. The wavelet coefficients provided by the multiresolution analysis of the high spatial resolution image A, between the scale of image A and the scale of image B, describe the missing information for the synthesis of the image B at the same spatial resolution than the one of image A.

The simplest solution is to shift the wavelet coefficients from pyramid A to pyramid B and to use them to synthesise image B at the spatial resolution of image A. If the wavelet coefficients provided by image A are used without modifications, the synthesised image B will not be equivalent to "what would be seen by sensor B if it had the spatial resolution of sensor A". Hence, to improve the quality of the synthesised image, the model, to transform the wavelet coefficients provided by the multiresolution analysis of image A in the wavelet coefficients needed for the synthesis should take into account the physics of the environment.

Whatever this model is, the ARSIS method preserves the spectral content of original image because of its very definition. A multiresolution analysis applied to the synthesised image B will allow the computation of an approximation similar to original image B.

Mangolini *et al.* (1995) and Wald *et al.* (1997) proposed a method to evaluate quantitatively the different sensor fusion techniques. ARSIS was shown to give the best results in terms of preservation of the spectral quality.

In the next section, the application of the ARSIS method to the merging of airborne and spaceborne imagery is proposed.

3 EXAMPLE

To prepare the SPOT 5 mission, the CNES, the French space agency, embarked a radiometer RAMI (Radiomètre Aéroporté Multispectral Imageur) on a Fokker 27 airplane(Anonymous, 1995). The airborne images are used to simulated the future SPOT-5 images. Our example deals with the town of Nancy located in the Northeast of France.

The original data, the B1, B2 and B3 images, were acquired, in June, 28, 1995 at the spatial resolution of 1.67 m with a spectral range of respectively 0.51-0.60 μm, 0.61-0.72 μm and 0.76-0.95 μm. From these images, were simulated first a panchromatic image at the spatial resolution of 1.67 m with a spectral range of 0.51-0.73 μm and the different images that will be delivered by the SPOT 5 sensor. For this sensor, the P band will have a spatial resolution of 5 m and a spectral range of 0.51-0.73 μm, and the B1, B2, B3 images will have a spatial resolution of 10 m and a spectral range of 0.50-0.59 μm, 0.61-0.68 μm and 0.79-0.89 μm respectively. Extracts of the P (at 5m) and B2 (at 10m) images are presented in Figure 3.

These images are used to illustrate the fusion process by the means of the ARSIS concept. By construction, they are perfectly co-registered. Accordingly, mis-registration does not interfere in this example. Blanc *et al.* (1998) demonstrated that a small residual in registration has a noticeable influence on the quality of products resulting from any fusion process performing on a pixel basis, including ARSIS.

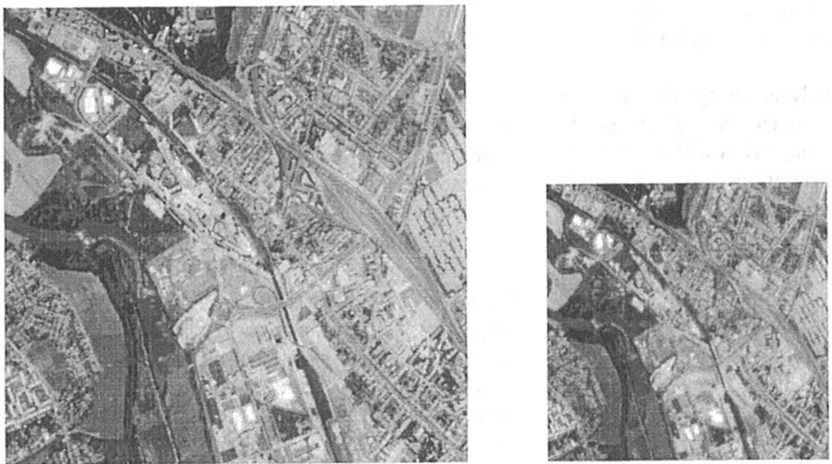
In a first step, the merging of the P image at 5 m with the Bi images at 10 m was performed and the Bi-HR images synthesised. In a second step, the merging of the P image at the spatial resolution of 1.67 m with the Bi-HR images synthesised at 5 m was achieved. Figure 4 presents the original and the synthesised B2 image at the spatial resolution of 1.67 m.

4 EVALUATION

To access the quality of the synthesised images, the approach proposed by Wald *et al.* (1997) was applied. In the case of the images from Nancy, it is possible to compare the synthesised images at the spatial resolution of 1.67 m with the original images acquired by the airborne campaign in a pixel-to-pixel basis. Table 1 presents quantitative results obtained from the set of images described previously.

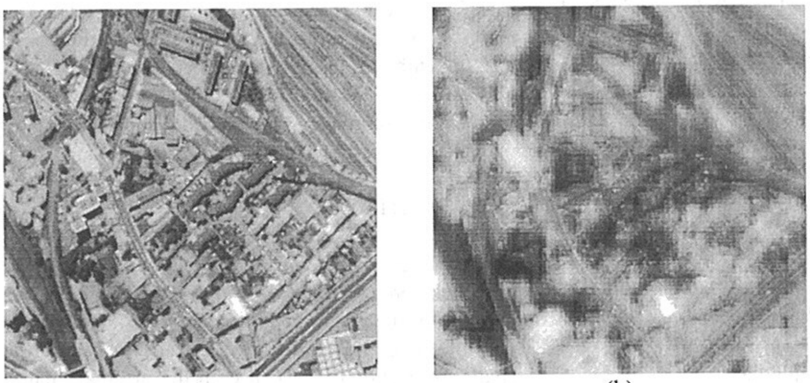
The bias represents the difference between the means of the original and the synthesised image. The difference in variances expresses the quantity of information added or lost during the enhancement of the spatial resolution. In this case, the lost of information due to the process is quite important. The correlation coefficient shows the similarity in small size structures between the original and the synthesised images. The standard deviation globally represents the level of error in any pixel.

The results obtained in this case are not as good as those usually obtained in the case of the merging



(a) (b)

Figure 3. (a) Extract of the simulated SPOT 5 P image at the spatial resolution of 5 m over Nancy, June 28, 1995; (b) Extract of the simulated SPOT 5 B2 image at the spatial resolution of 10 m over Nancy, June 28, 1995. Copyright CNES 1995.



(a) (b)

Figure 4. (a) Original airborne B2 image acquired by the RAMI system at the spatial resolution of 1.67 m over Nancy, June 28, 1995. Copyright CNES 1995. (b) Synthesised B2 image at the spatial resolution of 1.67 m.

of SPOT 1-3 XS (20 m) and P (10 m) images or of SPOT 5 B (10 m) and P (5 m) images (Wald *et al.*, 1997). The ratio between the satellite and the airborne images resolution is in this case of 6 and a lot of information has to be introduced from the 1.67 m P image in the 10 m Bi ones. In the case of the SPOT 1-3 imagery, the ratio is only of 2.

Table 2 confirms the results of Table 1. It represents the error at a pixel level. In this case, the percentage of pixels presenting a null error is low. This is in accordance with the very high dispersion of the value enhanced by the error in variance.

5 CONCLUSION

In this paper, the application of the ARSIS concept to improve the spatial resolution of satellite images using airborne images was proposed. This method allows from a high spatial resolution airborne image and a set of multispectral satellite images to

Table 1. Statistics on the differences between the original and synthesised images obtained for the Bi images at the spatial resolution of 1.67 m over Nancy, June 28, 1995.

	B1	B2	B3
Mean value of the original image	86	71	100
Bias (ideal value: 0) relative to the mean B value	31 35 %	4 6 %	0 0 %
Actual variance - estimate (ideal value: 0) relative to the actual variance	913 77 %	691 51 %	403 35 %
Correlation coefficient between B and estimate (ideal value: 1)	0.86	0.89	0.88
Standard deviation of the differences (ideal value: 0) relative to the mean B value	22 26 %	18 26 %	16 16 %

Table 2. Probability (in percent) for having in a pixel a relative error less than or equal to the thresholds noted in the first row. The ideal value is 100 as early as the first threshold 0.001 percent. The relative errors are in absolute value and in percent

	0.001	1	2	5	10	20	50	75	100
B1	0	0	1	2	4	12	95	**100**	100
B2	5	5	9	24	45	71	96	99	99
B3	4	9	16	35	55	77	95	98	99

construct a multispectral set of images with the spatial resolution provided by the airborne ones. The proposed method tries to preserve the spectral content of the original multispectral images. Is was usually applied to the synthesis of SPOT imagery. The quantitative assessment of the quality demonstrated that the method in its present form needs improvements due to the high ratio between both sets of images. The major improvement will certainly be in the model of transformation of the wavelet coefficients between the P and the Bi pyramids. But it was demonstrated that the ARSIS concept is of high generality and can be applied to most cases including the merging of airborne and spaceborne data. The perspectives of this work are firstly in the improvement of the quality of the synthesised image and secondly in the use of these images in applications requiring both the high spatial and the high spectral resolutions.

6 ACKNOWLEDGEMENTS

This work has been partly supported by the French Ministry of Défense (Direction des Systèmes de force et de la Prospective, service technique des technologies communes, département optronique) and by CNES (Centre National d'Etudes Spatiales).

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